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WASTES IN PRODUCTION

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CULLET USE IN THE PRODUCTION OF BUILDING MATERIALS

T. K. Pavlushkina[1, 2] and N. G. Kisilenko[1]

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Questions concerning the formation of cullet in the form of solid household wastes and at enterprises which reprocess sheet glass are examined. It is shown that cullet is promising for use in manufacturing materials used in different applications. Decorative facing materials — steklokremnezit, steklokeramit, pressed tiles, and smalt can be made with a wide range of colors, different configurations, and dimensions. Heat- and sound-insulating materials based on granular, tile, and block foam glass and slag foam glass are of practical interest.

Key words: cullet, solid household wastes, facing materials, foam glass, composite materials, steklokeramit, colored decorative tiles.

Special attention is now being focused on the efficient use of mineral resources in the production of different construction materials and articles. The problem of making efficient and comprehensive use of raw materials is inseparably linked with the level of industrial development and is of great importance for all industrially developed countries. The development and adoption of low-waste and waste-free technologies and improving the quality control of raw materials and finished products are directed toward decreasing wastes and losses of raw materials and materials all stages of their processing, storage, and transport and fuller use in the production of secondary resources and byproducts.

First and foremost, cullet is a valuable raw material. Partial substitution of cullet for batch permits decreasing noticeably the consumption of raw materials, some of which (for example, soda ash) are in short supply and expensive. According to a number of economists salvaging 1×10^6 bottles conserves 300 tons of quartz glass sand and 100 tons soda ash. For every 100 kg of cullet introduced 126 kg of primary raw material is conserved.

The introduction of cullet into batch is promising for decreasing energy consumption and saving fuel, since the silicate- and glass formation processes in melt proceed at lower temperatures; this is confirmed by many investigators. Thus, for glass obtained by melting batch the energy consumption was about 2×10^9 J/ton, while for glass obtained by remelting only cullet this figure does not exceed 1.5×10^9 J/ton. The calculations were performed for furnaces of the same type and the same temperature conditions and glass compositions [1].

In studying the possibility of conserving energy in the production of container glass, depending on the amount of cullet substituted in the batch for primary raw materials the conservation of energy not only for melting glass and fining the molten glass but also for obtaining, processing, and transporting raw materials was taken into account. It was found that every 10% increase of the amount of cullet in the batch results in the electricity conservation by 4.4 and 1.1%, respectively. According to other information, the fuel conservation is 0.25% per 1% cullet introduced.

The German firm Zippe GmbH, the leader in Europe, developed a design for a plant which salvaged cullet [2]. The technological arrangement of this plant formed the foundation of the typical lines developed.

The cullet flowing into special, secondary raw material bases are loaded into a hopper whence a vibrating feeder feeds into an inclined belt conveyer. The operator can regulate the feed rate of the cullet depending on the amount of contamination present in the cullet. An electromagnet is installed at the end of the conveyer to segregate metal inclusions.

In sorting segregation the operators work manually on a horizontal conveyer and remove the foreign inclusions consisting of ceramic, stones, paper, polyethylene, and others, which are then discarded into containers; cullet is fed into a hammer crusher that comminutes it to 8 – 30 mm size fraction. A screen is located directly under the crusher; the fine fraction of the glass and the adhered soil are separated on this screen from the rest of the cullet mass, and vacuum nozzles

[1] "Institut stekla," JSC, Moscow, Russia.
[2] E-mail: tpglass@mail.ru.

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are used to remove light-weight inclusions (aluminum caps, foil) from the required fraction. Next the prepared cullet is once again subjected to electromagnetic processing to finally remove the magnetic impurities and, using a conveyer, it is loaded into railroad cars for shipment to customers. The cullet processing capacity of such bases is 20 – 25 tons/h on average.

Some glass plants use, in addition, wet cleaning of crushed cullet to increase the light transmission of glass articles.

Ordinarily, manual sorting of glass by color (colorless and colored) is performed by the technological scheme described above. However, there are a number of technical solutions for automating the process of separating glass wastes by color. For example, in Germany a method and a facility using an electro-optic system have been proposed to separate container glass cullet from city and industrial wastes by color [3].

The method is based on measuring the in intensity of light which has passed through glass immersed in water with refractive close to that of glass in air. Water with added sugar, glycerin, and surfactants is used as such a liquid. The container with the liquid is placed in a special identification chamber with a mechanism for separating glass and with elevators for removing the separate cullet. Two pairs of radiation emitters and light detectors are built vertically into the bottom of the chamber. Light guides tie the emitters to a light source and a control circuit with a separation mechanism couples the detectors.

The apparatus described operates as follows: pieces of cullet enter the chamber through a receiving funnel. When colored glass enters the intensity of the transmitted light changes, and the electro-optic system generates a signal that is fed to the separation mechanism, which directs the glass into an appropriate hopper. The separation mechanism can be made in a mechanical or hydrodynamic variant. At the same time cullet is separated into colorless, brown, and green colors.

Many investigators are especially interested in the problem of separating and salvaging glass wastes in city dumps. The composition of the solid household wastes can change depending on the geographic position, time of year, and climate, and the level of development of the region.

City garbage contains the following: 6 – 9% magnetic and nonmagnetic metals, 35 – 43% paper, 5 – 12% plastic, 3 – 4% textiles, 16 – 19% food wastes, as well as ceramic, glass, and other materials. The glass content is, on average, 8 – 10% of the total amount of wastes.

As a result of this composition of city garbage there is a justification for processing if different materials can be separated, since the separation of one material is not cost-effective [4].

However, the directions of processing city wastes can be different depending on the local conditions. For example, in the USA the main thrust is to obtain fuel, magnetic metals, aluminum, and glass. There is much less interest in separating paper and cardboard. In European countries a great deal of attention is devoted to obtaining paper and plastics.

Cullet extracted from solid household wastes contains inorganic refractory impurities (corundum, mullite, quartz, porcelain, and others), admixtures of magnetic and nonmagnetic metals (cans, metal plugs, rings, and others), as well as organic impurities (paper, cardboard, plastics).

Particles of refractories entering molten glass do not completely dissolve in it. This serves as a reason for mass rejection of finished articles in the form of stones of different size. The metals and organic material can dissolve in the glass melt and give rise to an undesirable change in its color. For this reason cullet separated from city wastes and intended for secondary use must be processed in this manner so that when the cullet is used the glass quality would not change. The admissible limits on the content of impurities in the recovered glass are: ferromagnetic metals — 0.01%, nonmagnetic metals — 0.01%, organic inclusions — 0.05%, and inorganic impurities — 0.05%.

At the present time practically all European countries, the USA, Canada, Japan, and other countries have adopted a system of dry sorting of city wastes including the following basic stages: separation of ferromagnetic metals, separation and sorting of glass by color, separation of inorganic impurities (aluminum, stones, ceramic, and others), segregation of organic inclusions, and crushing glass.

Ferromagnetic metals are segregated by electromagnets placed, as a rule, above a belt conveyer, along which all entering wastes pass. Often, this operation is repeated twice: at the start of the process line before and after comminution of the glass.

The segregation of the light fractions (paper, cardboard, plastics, and others) from heavier fractions (glass, stones, nonmagnetic metals) is accomplished by means of a jet of suction air. The segregation of the stones, ceramic, nonmagnetic metallic inclusions (mainly aluminum) from glass at most operating plants is performed manually and partially combined with sorting glass by color.

Sometimes, these foreign inclusions are separated mechanically: vibrating screens, drums with spiral inner barrier, and other devices. The inorganic inclusions and cullet can also be separated by gravitational flotation, where to improve the conditions for flotation and ensure the most complete separation of the glass particles from the comminuted solid city wastes it is recommended that their surface be pre-activated by adding a water solution of compounds of bi- or trivalent metals (Ba, Ca, Al, Mg, and others). The largest effect from the use of activator ions obtains at pH = 3 – 12 for different metals. It is more effective to perform flotation in a mixture of water with sulfonates (alkyl sulfonate, aryl sulfonate, alkenyl sulfonate, and others), containing more than five carbon atoms (preferably 10 – 30). The amount of sulfonate introduced is 0.068 – 0.91 kg per 1 ton wastes. The optimal glass particle size is less than 2 mm.

After the magnetic inclusions are segregated the comminuted material is suppose to be passed along an inclined sur-

face of a steel plate on which it is separated because the coefficients of sliding friction of different inclusions are not the same. Next, to remove the nonmagnetic metals completely gravitational separation is performed in a salt bath and then a concentrate containing 99.0% glass (predominantly carbon as an impurity) is obtained by means of foam flotation.

However, these methods of mechanical sorting are not widely used because of they are not cost-effective.

It is entirely obvious that from the standpoint of efficiency and quality of screening of secondary resources, specifically cullet, sorting of solid household wastes (SHW) at their sources is preferable.

Thus, the following problems are solved:

– environmental: reduction in the consumption of natural resources by returning secondary materials into production and extending the service life of existing SHW dumps by decreasing the volume of wastes buried;

– aesthetic: adopting separate collection, which presupposes the use of eurocontainers and back-loaded garbage trucks, which fit into the city’s infrastructure more harmoniously, and are convenient for collecting and transporting wastes;

– economic: obtaining a profit from putting secondary raw materials to use and the expenditure of this profit on the future development of the waste handling system, as well as decreasing the cost of removing SHW for burial.

The experience of the “Steklo Resurs” Company which is the leading company in St. Petersburg in the field of collecting and sorting cullet merits attention. The company partners with the leading beer companies and glass producers in Russia and the countries of the Commonwealth of Independent States and has a wide network of receiving points for glass containers, which makes it possible to accumulate and store a large amount of sorted cullet. In 2006 the company delivered 20,000 tons of sorted cullet to glass enterprises producing glass containers.

This company solves an important environmental problem of any megalopolis — collecting dangerous types of waste — glass, which does not decompose in the ground. Centralized collection of broken glass and non-liquid bottles allows brewers and liquor producers to conveniently eliminate broken and rejected bottles and glass refuse as well as to remove from the city streets bottles that are unsuitable for the receiving points for glass containers.

In addition to the delivery of collected and sorted cullet the company offers processed European quality cullet. In this case the cullet is sorted by color. In the process all mechanical impurities and refuse are removed from it. Then the cullet is washed and crushed to particle size 50 mm. The cullet is allowed to contain corks, paper, and other organic impurities in amounts no more than 2%.

Cullet must be stored on special sites with a solid cover or in separate bays, which prevent contamination and mixing of grades.

The sheet-glass cullet sources are commercial glass-processing enterprises; cutting, mechanical working, tinting, mollifying, quenching, and hardening.

Specifically, in Moscow there are more than 50 organizations which fabricate articles from sheet glass: glass furniture, floors, glass packages, store window glass, doors, tinted glass, temperature glass, architectural glass, stain-glass windows, mirrors, and so on. A large quantity of waste is in the form of scraps, broken glass, and unusable articles.

The sheet-glass wastes can be recommended for use in the production of decorative facing materials.

The scheme for preparing cullet includes the following: collecting glass, crushing, removing foreign impurities, and comminuting to glass powder.

In organizations that produce hardened bulletproof glass and shockproof glass, specifically for glazing airplanes, banks, museums, pavilions, and so on wastes of so-called triplex, i.e., multilayer glass strengthened with an organic film, can accumulate. This glass cannot be crushed; surface cracks form on it. The interlayer film can burn out when the article is heated to a high temperature of the order of 600 – 750°C. Harmful organic components are released into the atmosphere, which requires exhaust ventilation equipped with a filtering system. In other words the processing triplex requires high-temperature energy-intensive equipment, multiple stages, and a complex process.

The simplest and widely used method of salvaging cullet is to introduce it into batch for making commercial glass (mainly container glass). The only novelty in this direction is a substantial extension of the limits of cullet content in batch, which can reach 90 – 95%. However, to ensure that the glass obtained is of high quality it is necessary to avoid introducing very large quantities of cullet of other colors and compositions. For example, up to 25% brown cullet, 10% white, and no more than 1% cullet with other colors can be introduced in batch to obtain green glass.

The use of cullet in other promising directions has been widely studied in recent years.

Comminuted cullet can be used as filler in road coatings in combination with asphalt and bitumen concrete. The best known is asphalt, tested in the USA [5], which can be used in cold weather. It contains 60% ground glass, 33% rock flour and 5% asphalt. Unsorted cullet can also be used to prepare it. The surfaces obtained have good structural properties; since glass retains heat well, “glassphalt” can be laid at lower temperatures than the standard mixtures. However, cullet consumption is very large. For example, 1450 tons cullet is needed to cover an approximately 300 m road.

The compositions and technology for producing colorless concrete with high operating stability (acid-resisting concrete), light concretes (cellular concrete) based on different types of cullet (picture tubes and electronic tubes, window and container glass, and others) have been developed at the V. V. Kuibyshev Moscow Civil Engineering Institute (Moscow). This technology can used to manufacture side-

walk slabs, edging, bricks, tiles for facing building socles, and other articles.

The articles obtained can be used as floor tiles in commercial and agricultural buildings and buildings with high corrosiveness of the medium.

Cullet screened into different fractions (large — 6.35 – 19.0 mm, average 1.4 – 6.35 mm, fine — < 0.18 mm) can used as an addition to Portland cement and polymers. The composition for obtaining composite material in combination with polymer includes cullet of different fractions in the following ratios (wt.%): large — 45, medium 25, fine — 30. Average content of cullet is approximately 20% but can reach 50%.

To improve the adhesion of glass to a resin- or cement-based matrix it is recommended that the cullet undergo preliminary processing. For example, for polyester resins the glass surface is modified using trimethyloxysilanes with the general formula $(CH_3O)_3SiR$, which interact with OH groups on the surface of the glass. In the case of vinyl polymers, a chlorine-containing organic complex of chromium has proven itself well. After the surface modification the glass granules are dried and mixed with a monomer, binding agent, and catalyst, after which molding and polymerization are performed. The final strength of the material depends on the grain composition of the cullet used and to a larger extent on the preliminary treatment (modification) of its surface.

The same tendencies are observed for a cement matrix. For example, a decrease of the compression strength by 25% after 18 months of storage at 20°C was observed in a sample containing 35% glass in a cement matrix with no additives. When 3% polyvinyl acetate emulsion under the same holding conditions was introduced the compression strength of the sample increased by 40%, even though the starting strength was lower.

Blocks with volume to 0.3 m^3 can be obtained from compositions based on glass and polymer wastes by the casting method. For a correctly chosen percentage content and definite grain composition of the glass no cracking and deformation of the castings is observed owing to the release of heat during polymerization of the resin.

Articles with a more complicated configuration can be obtained. For example, a flange with inner diameter to 12 cm was obtained from a mixture containing 0.195 – 1.4 mm cullet particles. Prior to introduction in a polyester resin the cullet was subjected to preliminary treatment. The indicated limits of the glass particle sizes were chosen so as to obtain the optimal combination of the compression and tensile strength.

Effective results were attained by using finely dispersed technical thermoplastics. The introduction of glass powder into paints increases their coverage, resistance to wear, and chemical action and imparts a definite texture to a surface. Glass powder can also be used as filler for rubber, increasing its durability and hardness.

Cullet combined with polymers or cements can be used to press tiles. The diversity and intensity of the color of tiles are obtained by introducing colorants in the form of solutions or dry additives with grinding. The colorant molecules are adsorbed on the glass surface and are not removed when exposed to water and ordinary solvents. It should be noted that the shear resistance of tiles with filler made of ground cullet is quite high (70 – 100).

The durability of tiles with cullet filler is very high: the losses (decrease of thickness) were 0.584 – 0.813 mm after 2500 revolutions with test speed 65 rpm and load 1 kg. For comparison the durability of high-quality finishing cement is 0.89 – 1.53 mm.

The positive effect of cullet on the properties of ceramic facing tiles is noted in works performed at NIIStroikeramika [6]. Introducing up to 30% ground glass into the press powder intensifies the sintering of the tile, decreases the moisture expansion of the tiles, and increases their frost resistance.

Cullet can be used to produce decorative panels. The light transmission of such panels based on polymers and colored cullet can vary over wide limits, but ordinarily it is 10 – 20% (λ = 5890 Å). They can be used as decorative barriers and covers. Multilayer panels with smooth exterior surfaces and filled by filler consisting of ground foam glass possess high acoustic and heat insulation properties and can be recommended for wall coverings in buildings.

Cullet is successfully used as an additive in fabricating bricks without any special requirements imposed on its quality. When 50% clay is replaced with cullet the firing temperature of the brick can be lowered from 1170 to 900°C. The capacity of the furnace increases by about 30%. High-quality bricks are obtained from a mixture of 30% cullet, 60% waste brick, and 10% clay. Such bricks have a high resistance to weathering and are suitable for use as facing materials.

The best method of salvaging cullet is production of heat- and acoustic-insulation tiles and composite building materials, specifically, different types of foam glass [7 – 14].

A foam glass with high heat-tolerance was been developed in Japan. This inexpensive material is manufactured from glass powder, liquid glass, and weakly alkaline slag.

Granular foam glass with a fused surface can be obtained from cullet. In this case the cullet is ground, wetted, granulated, dusted with ash, and sintered. Depending on the type of foam-glass granules ash or foam-glass wastes can be added to the batch mixture before granulation. The amount of ash dispersed in the granules can reach 75% of the mass of the granules [15 – 16].

Other methods of obtaining a cellular material, where the cullet is first ground in a ball mill to size 4 – 5 mm together with foam-forming additive, for example, soot, are available.

The mixture is sintered in the form of a dense material in a reducing atmosphere at 760°C and cooled. Then sintered mass is ground, passed through a sieve with cell size about 2 mm, and once again sintered in molds at 870 – 900°C, obtaining a cellular material which after removal from the furnace is extract from the mold and fired. The density of the material is regulated by varying the temperature and is 0.144 – 0.48 g/cm^3 on average. The advantage of this

method is that it permits rapid heating to the foaming temperature.

Foam-glass granulate with compression strength 4 – 12 MPa, intended for use as a filler for light concretes and manufacturing molded lightened building materials, is obtained from a raw material mixture which includes together with glass up to 85% pumice, lava, or tuff. Tuff and lava can be introduced simultaneously. The raw material is comminuted and mixed with organic pore-forming additives, after which raw granules of different size 0.1 – 1.5 mm are formed, dried at 600°C, and foamed in vibratory furnaces at 650 – 900°C in 5 – 180 sec. The foamed granules are removed from the furnace up to the moment when the bubbles can merge into large pores. For example, glass wastes are melted and the melt obtained is inflated into fiber, which is then comminuted into a thin powder. Next, a mixture consisting (wt.%) the following is formed: water — 100%, liquid glass — 32%, glycerin — 4%, sodium bentonite — 15%. It is mixed with powdered glass and raw granules about 1 mm in size are molded in a granulator. They are dried in a belt drier at 600 – 900°C, dusted with Al_2O_3 powder to avoid sticking, and foamed in a rotary vibrational furnace at 700°C. The size of the granules is 0.2 – 0.3 mm, the bulk volume mass is 100 – 500 g/liter, and the largest pore size is 0.1 mm.

Japanese researchers believe that the introduction of cullet improves the properties of slag wool [17]. When furnace slag is replaced by glass wastes (for example, container cullet) the tendency of the melt to spread decreases and the temperature range of slag wool production increases. The alkali-resistance of materials containing up to 60% cullet is satisfactory.

The "Institut stekla" JSC (Institute of Glass) in Moscow has developed and adopted a technology for producing long-lived and environmentally clean heat-insulation material — foam glass in the form of tiles, blocks, and granules, including the glassmaking base. The Institute also developed and synthesized glass for producing high-quality foam glass based on different types of initial natural raw material, cullet, and wastes from commercial production.

The Institute of Glass is one of the first to develop a technology for obtaining foam glass and can organize the production of modern heat-insulation material which is at least as good as the foreign analogues. The technology provides for flow-line production with a high level of mechanization, no commercial wastes, and no harmful emissions into the atmosphere. Complete production plants are equipped with most of the standard and unconventional domestic equipment.

An effective heat-insulation, water-resistant, and environmentally clean material with a cellular structure and low average density was developed in the Department of Technology of Separate and Insulation Materials at Moscow State Civil Engineering University on the basis of liquid glass and unsorted technical-glass cullet. The progressive "dry mineralization of foam" technology and rejection of energy-intensive autoclave processing make it possible to obtain articles from cellular concrete based on cullet, which are intended for heat-insulation of commercial and civilian buildings as well as commercial equipment and pipes with insulated-surface temperature to 600°C and higher [18].

The department also developed a method of finding the composition of foam concrete based on cullet and technological scheme incorporating the following: crushing–grinding division, division for preparing the mold paste, molding posts, heat treatment, holding and finishing articles, and dismantling and packaging. Tests performed on the material obtained in accordance with the operative GOSTs showed that the enclosing structures made of cellular concrete based on cullet with average density 400 – 900 kg/m^3 are not only at least as good as structures based on autoclave cement cellular concretes but also greatly surpass them. It should be mentioned that on the bases of cullet it is also possible to obtain dense fine-grain concretes, which possess high performance properties.

A definite advantage of the material obtained based on cullet is the fact that it can be produced by active enterprises in the construction industry which produce foam concretes without large capital investment. The cost-efficiency is also determined by the possibility of economizing Portland cement, sand, and coarse filler. It should also be noted that the price of cullet will change depending on its source. For example, the price of clean cullet purchased directly at the glass plants will fluctuate from 500 to 800 rubles per tone and will depend on the supplier, the distance from the glass plant, and the state of the market for construction materials at any given time. If the cullet is transported by truck from refuse processing plants, then it is necessary to take account of the costs of cleaning the cullet and averaging its composition.

Calculations show that the problem of reprocessing glass wastes in Moscow and Moscow Oblast' can be solved by one large plant producing cullet-based foam concrete articles with capacity 20,000 m^3/yr. According to the patent application [19], to obtain decorative tiles cullet is comminuted to 0.8 – 20 mm, poured in a 6 – 20 mm layer into metal molds coated with kaolin, and sintered at 750 – 900°C for 15 – 25 min depending on the composition.

Decorative facing articles can be obtained from a mixture containing 89 mass parts cullet and 1 mass part colorant based on zirconium. Smooth disks with diameter 40 mm are pressed from the mixture; these disks are sintered at 780°C for 1 h in stainless steel trays [20].

The authors of [21] propose using cullet in a mixture with carbonate ore to obtain boron-free, fluorine-free base-layer enamels which can be used as coatings for steel article of household and gas appliances.

It is recommended that wastes of container glass or borosilicate foam glass be used to obtain finely ground glass powder with particle size less than 0.44 mm, which combined with inert filler and binder in the form of ash of colloidal silicic acid form acid-resistant and heat-tolerant solution for setting foam glass blocks [22]. The recommended composition of the solution (wt.%) is as follows: glass powder — 26 – 60, filler — 23 – 61, binder — 13 – 45, with ration

1.8 : 1 – 2 : 1. Comminuted foam glass, quartz sand, or β-spodumene can serve as the filler. Blocks set on such a solution possess high heat-insulating properties, mechanical strength, and heat-tolerance. The bending strength of a seam, dried at room temperature, reaches 89% of the strength of the block itself. Under repeated thermal cycling from room temperature to 35°C the bending strength of such a seam decreases only to 80% of the strength of the block itself.

An effective building material based on glass wastes with addition of natural mica has been developed in Canada [23]. Container glass cullet which is pre-crushed and then ground to the fraction 150 – 300 μm is used for these purposes. The glass powder obtained is mixed with ground mica powder with the same grain size and wetted to 6%. The mixture is used to press blanks, which are annealed for 60 – 120 min in a furnace at 700 – 1000°C. The materials obtained possess high mechanical strength and frost resistance.

The authors of [24] have shown that it is desirable to use electro-vacuum glass cullet to fabricate low-voltage electro-technical porcelain. It has a positive effect on very important electro-ceramic properties, such as the tangent of the angle of dielectric losses, the volume resistance, and the electric strength.

A technology for obtaining facing materials — glass-marble and foam-dekor [25 – 26] based on unsorted salvaged glass with no corrective additives — has been developed at Minsk Institute of Construction Materials on the basis of container-glass and top-quality dishware wastes.

A technology for obtaining an effective facing material — steklokremnezit, obtained by sintering a mixture of glass-granulate and quartz sand with a decorative layer made of colored granules as well as a technology for porokremnezit — differing from the latter material by a lower volume mass [27 – 29] have been developed at the Lenin glass plant.

An experimental batch of the effective decorative-facing material "Ékstragranit" using cullet and quartz sand possessing high performance properties has been produced at the Scientific–Industrial Association "ÉKSTRASTEP."

The greatest effect is attained using an extra-granite for facing socles of commercial, public, merchant, cultural-entertainment, sports, and other buildings to protect them from damaging actions.

A technology for facing tiles ("avantyurina") based on glass wastes with additions of chromium and copper oxides has been developed at the Dnepropetrovsk Chemical-Technological Institute [30].

A technology for facing construction materials making it possible to salvage non-recyclable wastes from the production of reinforced glass, triplex, and slag-sital has been developed at the NIIavtosteklo. Compositions for opacified colored glasses and a black color for marblite have been developed [31].

The composition and technology for producing an effective heat-insulation material "Kremnepor," which contains ground glass as filler, have been developed at the Bor Glass Works. This material has successfully completed testing at several nuclear power plants in the form of a warmer on the roofing of machine rooms [32].

A very promising and cost-effective direction is to use cullet in a mixture with slag for preparing different porous insulation materials [33 – 36].

A new decorative-facing material steklokeramit has been developed at the "Institute of Glass" JSC. It consists of a two-layer composite material obtained by heat-treatment at 930 – 960°C of a ground mixture of glass and clay. The decorative properties of the new material are similar to the previously produced steklokeramzit, and its physical-mechanical and technical-economic performances surpass the latter's considerably.

The bottom layer (substrate) of steklokeramzit, consisting of the ingredients listed above, is a sintered monolith, which possesses a rough surface to ensure its adherence to building structures. The substrate can be fabricated using purchased cullet meeting to the industry standards. The presence of negligible quantities of inorganic contaminants (refractories, clay, and sand) does not play a negative role in using cullet in the production of steklokeramzit.

The technology makes it possible to obtain not only tiles with the correct geometric shape in the form of squares and rectangles but also articles of different configuration and dimensions, prescribed mold contours for firing, which greatly expands their range of application.

A decorative layer of colored glass powder is deposited on the front surface of the tile.

A technology for obtaining decorative facing tile by pressing comminuted colorless or colored cullet, uniform or a mixture of two or more types or uniform with colorant added in the bulk has also been developed at the Institute. Such a tile is fired in the temperature range 700 – 850°C and is characterized by uniform color in the bulk or multiple colors with a nonrepeating figure or with the facing surface decorated with paints [37]. It is also of interest to develop new types of facing materials, based on glass wastes, distinguished by a diverse color range [38] and an aventurine effect [39].

Cullet is a valuable secondary raw material, whose use is of great practical value from the stand point of economizing raw materials and fuel-energy resources as well solving the problems of environmental protection.

In industrially developed countries serious attention is given to collecting and processing glass wastes. This is done by specialized firms, which organize the collection of containers and other glass wastes, providing for reprocessing of cullet (cleaning, sorting, and so on) and delivering color-sorted cullet with a definite particle size with the minimum content of iron and other inclusions to customers.

Complete processing of city trash with extraction of glass wastes is also cost-effective. The technology for reprocessing cullet has now reached a level where enrichment of cullet is cost-effective and worth its full value.

The existing directions for using cullet include the conventional method of using it in batch for secondary glassmaking. The introduction of elevated quantities of cullet (to 90 – 95%) conserves substantial quantities of raw materials (primarily soda ash) and fuel. At the same time this will result in some changes in the technology of making such glass (change of the temperature regime of the furnace, melting and fining time for the molten glass, and the properties of the manufactured glasses).

In summary, the salvaging of cullet, a large amount of which is present on the entire territory of Russia, makes it possible to solve a number of production problems and improve the environment in industrial regions, while waste-free environmentally clean energy-conserving technologies will give a large economic effect.

REFERENCES

1. H. Moore, "Glass container technology," *Glass Technol.*, **64**(2), 14 – 17 (1983).
2. H. Moser, "A complete plant," **56**(5), 152 – 157 (1979).
3. *FRG Patent No. 320 7447. MKI S 038 1/00. Method and Facility for Identifying and Separating Cullet According to Optical Properties*.
4. P. D. Sarkisov, R. M. Chernyakova, and P. D. Petrov, "Extraction of glass from solid city wastes," in: *Glass Industry* [in Russian], VNIIÉSM, Moscow (1986), Issue 8, pp. 13 – 15.
5. I. J. Miller and M. D. Bailey, "Uses for waste glass as survey," in: *Report*, No. 2289, p. 33.
6. S. N. Zotov, "Investigation of the effect of different types of cullet on the properties of ceramic articles," in: *Glass Industry* [in Russian], VNIIÉSM, Moscow (1986), Issue 58, pp. 24 – 25.
7. B. K. Demidovich and G. K. Fisyuk, "Decorative-acoustic foam glass," *Ref. Inform., Stekol. Prom-st',* No. 6, Ser. 9, 6 (1985).
8. D. V. Damdinova, A. D. Tserimpilov, and I. I. Budaeva, *Method for Obtaining Foam Glass, RF Patent No. 2291845 SOZS 011/00* [in Russian].
9. A. S. Rossomagina, I. S. Puzanov, and A. A. Ketov, *Chemical-Technological Principles of Foam Glass Production from Cullet* [in Russian], Sputnik, Moscow (2003), p. 321.
10. L. I. Dvorkin and O. L. Dvorkin, *Building Materials from Industrial Wastes* [in Russian], Feniks, Moscow (2007).
11. G. B. Ketova, A. I. Puzanov, I. S. Puznov, et al., "Problems of secondary use of cullet and ways to solve them," in: *Promyshlennaya Ékologiya na Rubezhe Vekov* [in Russian], Perm' (2001), pp. 247 – 252.
12. A. S. Belokopytova, *Development Processes for Salvaging Cullet by Developing Composite Materials, Author's Abstract of Candidate's Thesis* [in Russian], Moscow (2006).
13. A. A. Ketov, G. B. Ketova, A. I. Puzanov, et al., "Cullet as raw material for obtaining heat-insulation materials," *Ékologiya Prom-st' Rossii*, No. 8, 17 – 20 (2002).
14. Yu. A. Guloyan, *Technology of Glass and Glass Articles* [in Russian], Vladimir (2003).
15. B. K. Demidovich and S. S. Iodo, "Granular foam glass," *Ékspress-inform. Stekol. Prom-st'. Otechestvennyi Opyt*, Ser. 9, No. 4, 13 (1985).
16. L. B. Smirnova, "Granulated glass," *Steklo Keram.*, No. 12, 22 (1990).
17. *Furnace Slag in Mixtures with Glass Wastes, Japan Patent 56-37249, MKI C 03C 13/00*.
18. E. I. Zaitsev, *Porized Heat-Insulation of Cullet-Based Material, Author's Abstract of Candidate's Thesis* [in Russian], MGSU, Moscow (1998).
19. *Method of Producing Decorative Glass Articles from Glass Wastes, Bulgaria Inventor's Certificate 30061, MKI C 03 B 17/00.*
20. *Decorative Facing Glass Articles, Japan Patent 53-140313, MKI C 03 B 17/00*.
21. A. V. Sarukhanishvilli and I. G. Zedginidze, "Investigation of the industrial wastes in boron-free and fluorine-free base-layer enamels," *Steklo Keram.*, No. 4, p. 6 (1987); A. V. Sarukhanishvilli and I. G. Zedginidze, "Using industrial wastes in boron-free and fluorine-free ground enamels," *Glass Ceram.*, **44**(4), 137 – 139 (1987).
22. *Acid- and Heat-Resistance Solution for Setting Foam Glass Blocks, Great Britain Patent 1525777. MKI C 03 B 19/00*.
23. N. M. Low, "New building materials based on natural mica and glass wastes," *Ékspress-inform. Stekol. Prom-st'*, No. 1, Ser. 4 (1983).
24. L. P. Gavrikova, V. D. Konerskii, G. N. Maslennikova, and V. D. Beshentsov, "Cullet use in electro-ceramics," *Steklo Keram.*, No. 7, 6 – 7 (1987); L. P. Gavrikova, V. D. Konerskii, G. N. Maslennikova, and V. D. Beshentsov, "Using glass cullet in electrical ceramics," *Glass Ceram.*, **44**(4), 278 – 282 (1987).
25. B. K. Demidovich, "New technology for producing finishing material from glass," *Ékspress-inform. Stekol. Prom-st'. Otechestvennyi Opyt*, Ser. 9. No. 7, 9 (1985).
26. B. K. Demidovich, "Production of penodekor — facing material from foamed glass," *Ékspress-inform. Stekol. Prom-st'*, Ser. 9. No. 9, 6 – 7 (1985).
27. V. F. Lyasin and V. D. Sarkisov, *Facing Glass and Glass Crystal Materials* [in Russian], Vyssh. Shk., Moscow (1988).
28. V. Yu. Reznik, "Method of fabricating decorative-facing tiles and a facility for their continuous production, RF Patent 216896," *Byul. Izobr. Polezn. Modeli*, No. 14 (2001).
29. V. Yu. Resnik, "RF Patent 2169709," *Byul. Izobr. Polezn. Modeli*, No. 16 (2001).
30. M. D. Shcheglova, "Decorative-facing tiles based on glass wastes," in: *Use of Industrial Wastes and Byproducts in the Production of Building Materials and Articles*. *Environmental* Protection [in Russian], VNIIÉSM (1988), Ser. II, No. 8, p. 19.
31. V. G. Gomozova, V. I. Kiyan, R. S. Zolotorea, and L. V. Artamonov, "Facing tiles from marblite based on industrial wastes," *Steklo Keram.*, No. 5, 7 – 8 (1989); V. G. Gomozova, V. I. Kiyan, R. S. Zolotorea, and L. V. Artamonov, "Marblite facing plates based on industrial wastes," *Glass Ceram.*, **46**(5), 182 – 183 (1989).
32. A. B. Zhimalov, *Development of the Composition and Technology of Heat-Insulating Material "Kremnepor," Author's Abstract of Candidate's Thesis* [in Russian], Moscow (1988).
33. V. F. Pablov, "Method of producing porous glass materials from martensite slags, RF Patent No. 2132306," *Byul. Izobr. Polezn. Modeli*, No. 18 (1999).
34. V. F. Shabanov, V. F. Pavlov, I. V. Pavlov, et al., "Method of producing porous glass materials from slags, RF Patent No. 2132306," *Byul. Izobr. Polezn. Modeli*, No. 31 (1999).
35. G. Ya. Dobrosetskaya, *Synthesis of New Facing Materials Based on Glass and Slag by Sintering, Author's Abstract of Candidate's Thesis* [in Russian], Moscow (1982).
36. T. K. Pavlushkina, "Colored decorative facing materials based on glass," *Glass Russia Steklo*, January, 16 – 18 (2011).
37. T. K. Pavlushkina, V. V. Limitovskii, and I. V. Morozova, "Decorative Facing Tile, RF Patent for useful model 69514, CO3C 6/02, VNIIS 5/04," *Byul. Izobr. Polezn. Modeli*, No. 36 (2007).
38. S. V. Ignatov, I. V. Kulakov, T. K. Pavlushkina, and S. I. Ryzhenkov, "Decorative facing tile, RF Patent for useful model 47003, CO3C 17/28," *Byul. Izobr. Polezn. Modeli*, No. 22 (2005).
39. T. K. Pavlushkina, Ya. É. Banyuk, I. V. Morozova, and S. V. Ignatov, "Glass decorative facing tile, RF Patent for useful model 96117, CO3C 17/04," *Byul. Izobr. Polezn. Modeli*, No. 20 (2010).